LCA Case Studies

LCA of an Italian Lager Beer*

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Abstract

Background, Aim and Scope. The increasing concern about environment protection and a broader awareness of the sustainable development issues cause more and more attention to be given to the environmental impacts of products through the different phases of their life cycle. Foods are definitely among the products whose overall environmental performance can be effectively investigated resorting to LCA. A LCA case study was performed in order to detect and quantify the environmental impacts deriving from the life cycle of a lager beer produced by an Italian small brewery, investigating and comparing two packaging options: beer in 20 L returnable stainless steel kegs and beer in 33 cL one way glass bottles.

Materials and Methods. The investigated system included: production and acquisition of materials and energy, brewing process, packaging, transports, beer consumption and waste disposal. Data for the study were mostly collected from the Theresianer Brewery and completed on the basis of literature information. Data uncertainty was treated with a Monte Carlo analysis. Life Cycle Inventories were constructed for 1 L of beer in bottle and 1 L of beer in keg using the LCA software SimaPro and then assessed at the endpoint level according to the Eco-Indicator'99 method.

Results. Inorganic emissions, land use and fossil fuel consumptions resulted to be the most critical environmental issues of both beer life cycles. Beer in keg turned out to cause a lower environmental load along its life cycle than bottled beer; this was mainly due to the higher emissions and the higher energy consumptions allocated to the glass bottles. Moreover, beer consumption phase, glass bottle production and barley cultivation were found to be the critical stages of the beer life cycle.

Discussion. The brewing process did not result as a critical stage and therefore the company dimension may not be a crucial element for the overall impact quantification. On the contrary, beer consumption may have a significant impact mainly due to the consumer displacement.

Conclusions. The analysis pointed out the relevance of the beer consumption phase and of the packaging choice within the beer life cycle and allowed to detect the other critical stages of the life cycle. It is worth to notice that producers and consumers can be active and responsible actors in pursuing the collective goal of the environmental sustainability.

Recommendations and Perspectives. In order to improve the environmental performance of the beer life cycle, producers should set up marketing strategies in favour of reusable packaging and consumers should prefer draught beer and reduce car use. As beer consumption phase, bottle production and recycling and barley cultivation were found to be very significant stages of the life cycle of the beer, deepening the analysis of these aspects in similar studies is suggested.

Keywords: Beer; bottle; brewery; Eco-Indicator'99; environmental performance; food consumption; Italy; keg; packaging; product LCA

Introduction

The increasing concern about environment protection and a broader awareness of the sustainable development issues cause more and more attention to be given to the environmental impacts of products through the different phases of their life cycle, such as manufacturing, distribution, use and, when appropriate, to the fate after use. As a consequence, for products as well as processes and services the concept of life cycle, i.e. of a study approach from cradle-to-grave, is more and more applied to support both strategic and operational choices.

Even if some methodological aspects are still under discussion, the practical use of Life Cycle Assessment (LCA) is wide-spreading to analyze, with different goals, a larger variety of situations. Foods are definitely among the products whose overall environmental performance can be effectively investigated resorting to LCA [see for all 1–6].

The LCA methodology is applied here to the beer life cycle in order to find out the consequences of an ordinary act like drinking this beverage. As a case study, the lager beer produced by a small brewery in North-East Italy was analysed assuming that the marketed products were beer in 20 L returnable stainless steel kegs, used for draught beer, and beer in 33 cL one way glass bottles: these two alternatives, available to consumers, were compared considering their whole life cycle, starting from barley cultivation and accounting for the packaging production and disposal.

It is worth noting that while there is a wide body of scientific and technological literature on beer production [see for all 7–10], only a limited number of LCA studies are avail-

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able for the beer production [11–13]. Unlike the cited LCAs, the present study considered also consumption stage and kegged beer. Furthermore, attention was focused on endpoint impact categories [14], according to Eco-Indicator'99 [15], in order to compare the two packaging types. Moreover, suggestions for environment preservation and environmental impact control and reduction were derived both for the production phase and for the use one as required by the awareness that producers and consumers have to be active and responsible actors in pursuing environmental sustainability.

1 Goal and Scope Definition

The aim of this LCA study was to analyse the input-output (I/O) streams of beer production, to assess the impacts deriving from its life cycle and to detect the critical stages. The analysis was performed on two kinds of packaged product: beer in 20 L returnable steel kegs and beer in 33 cL one way glass bottles. This allowed in a further step the comparison between the two alternatives in order to verify the environmental preferable one. Finally, some suggestions for improvement were provided.

2 Materials and Methods

2.1 Functional unit and system boundaries

The product analysed is an Italian lager beer produced by a small brewery (about 1,880,000 L per year). The functional unit chosen to represent the system was defined as 1 L of beer and the fraction of packaging allocated to such a litre (1/20 of a 20 L steel keg or three 33 cL glass bottles).

The system boundaries for the analysis were not restricted to the brewing process but, following the LCA approach, included also the upstream and downstream phases. Thus, the system studied included: the agricultural processes of barley and hop cultivation; the production of malt and beer; the production of packaging and auxiliary materials (oxygen, carbonic dioxide, phosphoric acid, calcium chloride, filtering earth, cleaning products); the transport for distribution to a consuming point; the final disposal of packaging (supposed to be recycled); the treatment of wastewaters and the production of heat and electricity. The whole system is represented in **Fig. 1**: since roots, spent grains and yeast excess are by-products that occur during malting and brewing processes they were considered as an avoided production of cattle feed, that definitely is their actual fate.

The present case study was analysed at two different Levels: Level 1 neglected the beer consumption phase (i.e. beer refrigeration, beer dispensing, consumer displacement and treatment of consumer wastewater), while in Level 2 this limitation was removed. This choice was due to the uncertainties involved in the consumption stage which reduce the reliability of the results. Use phase scenarios are indeed extremely variable and a precise determination would have required an onerous investigation; however, because of the interest this stage covers in a LCA study, an estimation of its impacts was assessed and the results were presented in the Level 2 analysis.

As beer and malt were the two main material flows occurring in the system, their packaging were investigated in details including primary packaging (that wrap a single unit of product), secondary packaging (that bundle several units of product) and tertiary packaging (that are fixed up for delivery). For all the other materials, present in smaller quantities, only primary packaging was considered.

Furthermore, the production of yeasts and materials employed in negligible amounts in the brewery (such as silica gel and PVPP) were not included in the system boundaries since their potential influence on the analysis results can safely be assumed as negligible. Finally, also manufacturing and disposal of capital goods, nonmaterial values, costs and human resources were not considered.

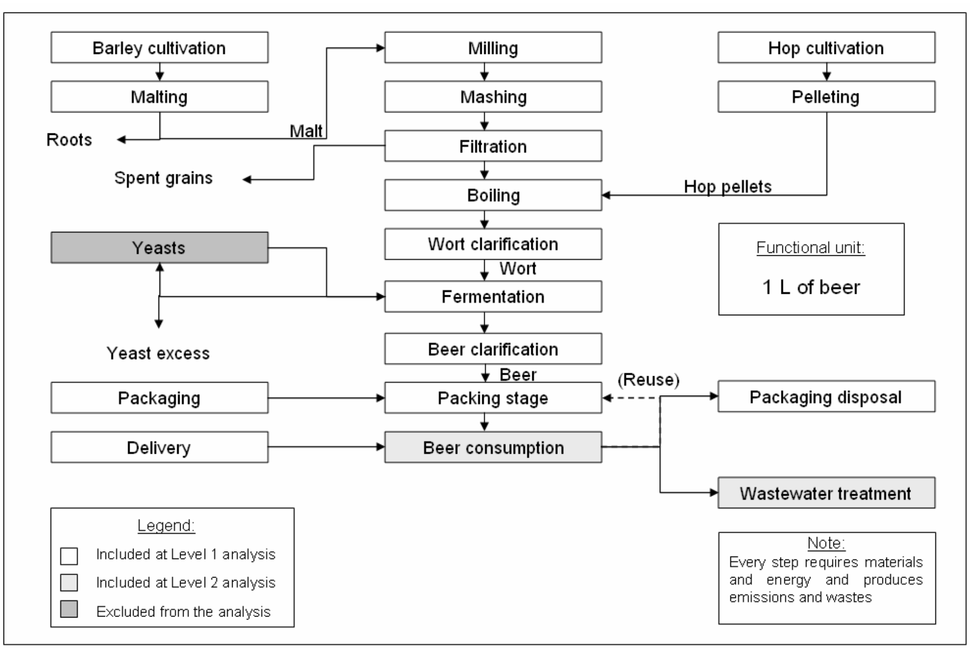

Fig. 1: Beer life cycle scheme

2.2 Data collection

The most of the data about the brewing process were obtained from the Theresianer brewery and referred to the year 2004 operations. It is well known that data collection is an onerous step in a LCA study and that finding all the required specific data results difficult without resorting to some approximations: this is more apparent in the case of a Small Medium Enterprise (SME), as the company involved in the study. Foreground data were therefore integrated with literature data [10, 16–18], database information [19–21] and expert judgements [22], striving to match the real spatial-temporal dimension and the technology level. The main data sources are summed up in **Table 1**.

Each uncertain datum was expressed by its most probable value and an associated range of uncertainty (e.g. defined by the upper and the lower limits in triangular distributions or by the standard deviation in log-normal distributions). Data uncertainty was then treated with a Monte Carlo analysis [23] (see par. 2.3).

As an example, water (L/L of beer) and energy (MJ/L of beer) consumptions considered for the brewing process are reported in **Table 2** specifying ranges used to define their triangular distribution.

2.3 Methods

Once data were collected, 40 unit processes were defined 'ad hoc' to model the whole system, devoting 5 of them to brewing operations. From the resulting model, Life Cycle Inventories were constructed for 1 L of beer in bottle and 1 L of beer in keg; for both the options considered, LCI were set using the LCA software SimaPro and then assessed using the Eco-Indicator'99 method [15].

In the Eco-Indicator'99 method, eleven impact categories are added into three damage categories (also named Eco-Indicators) and then normalised, weighted and aggregated into an index, the Single Score, that represents the overall environmental load of the life cycle.

In order to account for subjectivity of the impact assessment procedure, Eco-Indicator'99 presents three different approaches. These criteria, based on the Cultural Theory of Thompson [24], are significant of different cultural perspectives and are identified as Egalitarian (E), Hierarchist (H) and Individualist (I). Every perspective has a different impact perception, different normalising factors and different weights and, thus, leads to different results. The Egalitarian and the Individualist approaches are based on a perception of the reality more radical than the Hierarchist one, which, due to its moderation, is therefore recommended as a default.

No matter the perspective assumed, Eco-Indicator'99 had to be modified to include groundwater consumption in the Resources damage category since water was a significant material flow in the beer life cycle, while the original method considered water as an unlimited resource regardless of its source.

Table 1: Data sources of the analysed processes

Analysed process	Data source
Production and acquisition of raw and auxiliary materials	Brewery needs lots of materials (e.g. barley malt, phosphoric acid, cleaning, agents). Quantities and supplier distances from the brewery were given by the producer or found in literature; I/O data derived from Ecoinvent database. In particular, barley, the foremost material used to produce beer, was cultivated in Germany and was described by the Ecoinvent process 'Barley grains extensive at farm' that has a yield of 5,550 kg/ha at a 15% of moisture.
Beer production	The several stages of the brewing process were modelled from specific and literature data for hop pellet production, malting, wort production, wort fermentation and beer clarification, packing and auxiliary processes. 1 L of bottled beer required on average 269 g of barley, 707 mg of hop, 7.9 L of water, 3.52 MJ of energy with slightly lower values in the case of keg, as the result of reduced losses in filling the container. Moreover, a use as cattle feed was considered for the small amount (little less than 30 g/L as cattle feed equivalent) of by-products from the malting and brewing processes.
Packaging	Each empty bottle weighed 230 g, on average 3,045 bottles of glass were considered needed by 1 L of beer. Bottle production and disposal (recycling) I/O data were got by Ecoinvent database. Steel kegs weighed 8.8 kg and on average they were reused 85 times before their disposal (recycling). I/O data were got from Ecoinvent database.
Transport processes	Transport processes I/O data derived from Ecoinvent and ETH-ESU 96 databases. Transport distances were supplied by the brewery, in particular it was considered that beer was freighted, on average, for 200 km.
Energetic processes	Energetic processes I/O data derived from Ecoinvent and ETH-ESU 96 databases. Energy demands were supplied by the brewery or were esteemed from literature.
Disposal treatments	Waste recycling and wastewater treatments were derived from Ecoinvent processes. Transport to disposal plants were considered, too.

Table 2: Water and energy consumption: minimum, average and maximum values for the distinct stages of the brewing process

Process	Energy (MJ / L of beer)						Water (L / L of beer)					
	Min.		Average		Max.		Min.		Average		Max.	
	Bottle	Keg	Bottle	Keg	Bottle	Keg	Bottle	Keg	Bottle	Keg	Bottle	Keg
Malting	0.841	0.84	**0.857**	**0.856**	2.08	2.08	0.824	0.8	**1.03**	**1**	1.236	1.2
Wort production	0.893	0.892	**0.952**	**0.951**	0.965	0.964	1.47	1.45	**1.47**	**1.45**	1.47	1.45
Fermentation and clarification	0.107	0.104	**0.121**	**0.118**	0.421	0.41	0.245	0.236	**0.27**	**0.26**	0.295	0.284
Packing	0.295	0.252	**0.353**	**0.301**	0.388	0.331	0.9	0.1	**1**	**0.2**	2.1	0.5
Auxiliary processes	1.05	1.05	**1.24**	**1.24**	1.41	1.41	2.8	2.8	**4.1**	**4.1**	6.4	6.4
TOT.	3.18	3.14	**3.52**	**3.47**	5.27	5.2	6.24	5.39	**7.87**	**7.01**	11.5	9.83

As previously stated, data uncertainty was treated with Monte Carlo analysis [23]. This method allowed to establish an uncertainty range in the LCA results by repeating the calculation runs with values that follow the probability distribution of the starting data.

3 Results and Discussion

3.1 Level 1 comparison

In the Level 1 analysis, impacts deriving from both the life cycles were assessed with Eco-Indicator'99 in the Hierarchist perspective. The results obtained are summarized in **Table 3** in order to make easier the numeric comparison between the performances of the two life cycles.

The damages to Human Health, Ecosystem Quality and Resources were found to be mainly due to inorganic emissions, land use and fossil fuel consumption in both the life cycles. Of course, since the brewing process is common to both the investigated options, differences in the results are attributed to the weight of contributions on the beer life cycle of the different packaging modes.

For the bottled beer, glass bottle life cycle had a significant role (about 42% of the damages to the Human Health and the Resources categories), while transports and brewery demand of energy assumed relevance in the life cycle of kegged beer (respectively about 51% of the Human Health damage category and 39% of the Resources damage category). Barley cultivation was the process mainly responsible of the damage to the Ecosystem Quality (about 96% in the bottled beer life cycle and 98% in the other case).

Single Scores derived from the aggregation of the previous damages were respectively 135 mPt for 1 L of beer in bottle and 92.9 mPt for 1 L of beer in keg.

As a matter of facts, the beer in keg caused lower damages and was responsible for an estimated overall environmental load which is about 68% lower than the one associated to the beer in bottle. The difference between the two life cycles can be pointed out comparing the single impact categories: as reported in **Fig. 2**, the beer in keg showed lower impacts than the beer in bottle in each category with the exception of Ecotoxicity and Minerals that, however, had a marginal role.

Table 3: Level 1 characterization and evaluation of the two life cycles with the three perspectives of EcoIndicator'99

Perspective	Hierarchist		Egalitarian		Individualist	
Beer life cycle	1L in bottle	1L in keg	1L in bottle	1 L in keg	1L in bottle	1 L in keg
Human Health (DALY)	$1.55 \cdot 10^{-6}$	$9.45 \cdot 10^{-7}$	$1.56 \cdot 10^{-6}$	$9.48 \cdot 10^{-7}$	$7.33 \cdot 10^{-7}$	$4.35 \cdot 10^{-7}$
Ecosystem Quality (PDF·m^2·yr)	$4.87 \cdot 10^{-1}$	$4.63 \cdot 10^{-1}$	$4.87 \cdot 10^{-1}$	$4.63 \cdot 10^{-1}$	$4.77 \cdot 10^{-1}$	$4.37 \cdot 10^{-1}$
Resources ($MJ_{surplus}$)	2.38	1.35	1.49	$8.68 \cdot 10^{-1}$	$3.1 \cdot 10^{-2}$	$9.41 \cdot 10^{-2}$
Single Score (mPt)	135	92.9	128	92.7	117	179

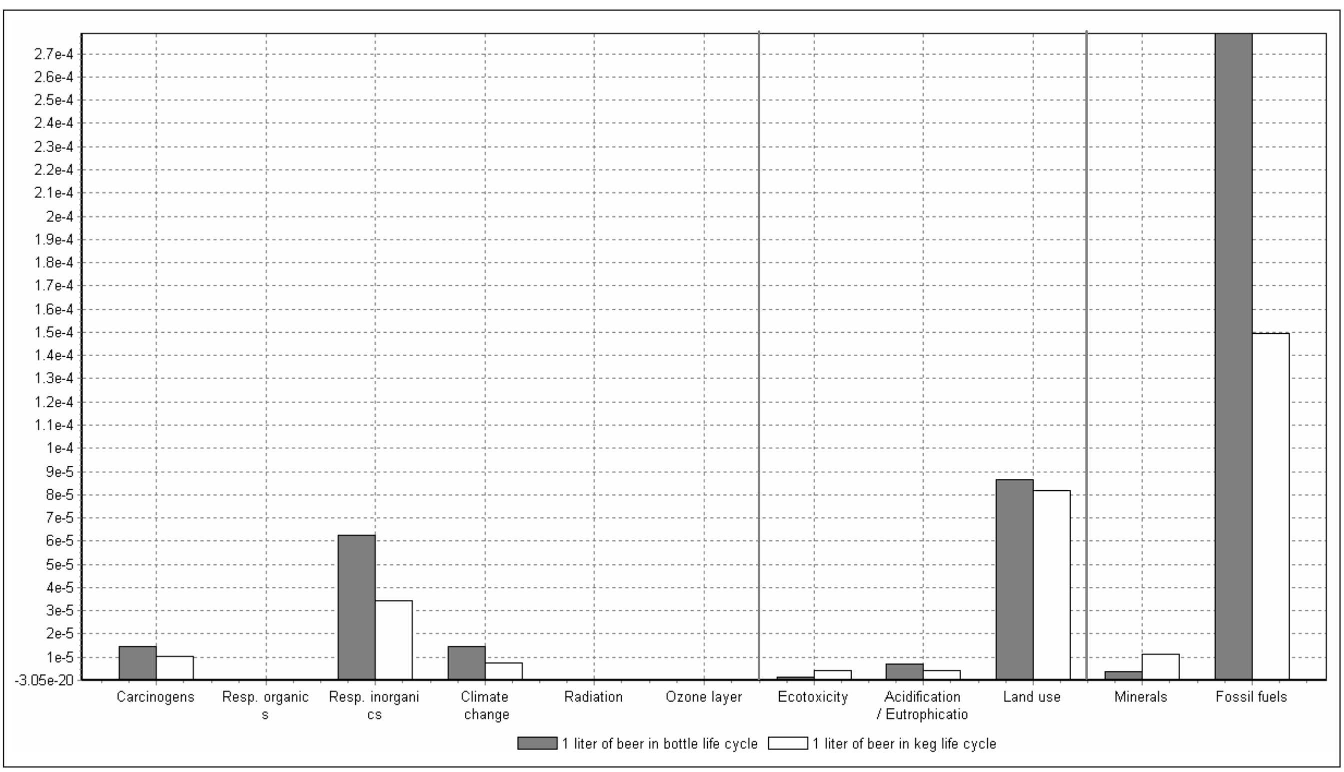

Fig. 2: Comparison of the normalized impact category values for the two life cycles

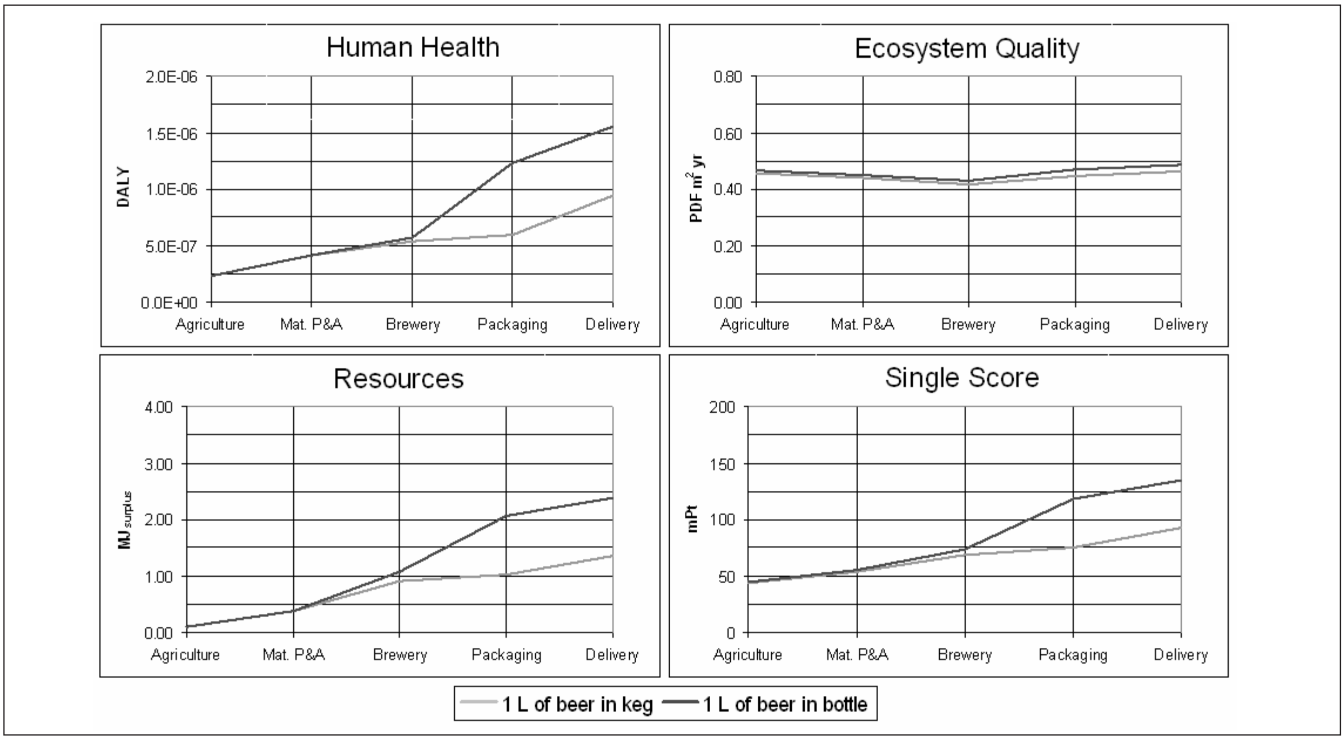

Fig. 3: Cumulative values over the life cycle subsystems for the three Eco-Indicators and the Single Score

In order to have a more synthetic representation and a better perception of the differences between the two investigated options, both the life cycles were split in the following five subsystems:

- Agricultural process of barley cultivation;
- Raw material production (except barley) and acquisition;
- Brewery operations;
- Beer packaging (production, transport and disposal);
- Product delivery (on a distance of 200 km).

For each of them the contribution to the three damage categories and to the Single Score was evaluated. Results for the single subsystems were then recombined to represent the cumulative values over the life cycle, as reported in **Fig. 3**. For each impact category as well as for the Single Score, it is apparent that the performances of the two life cycles overlapped till the beer production subsystem and that then they diverged once the packaging subsystem was included. The difference, which also affected the overall results, occurred because of the largest effects resulting for the bottled beer; actually, the life cycle of the bottles allocated to 1 L of beer, produced more emissions and required more energy than in the case of the fraction of reusable keg used for the same task.

From a scrutiny of the results reported in Fig. 3 some conclusions holding for both the two life cycles can also be drawn:

- beer production did not seem to be a worrying stage, consistently with the widely held opinion that breweries have to be considered among the less energy consuming and less polluting activities in the industrial sector;
- contribution of barley cultivation was quite significant for the Ecosystem Quality damage and the overall environmental load because of the large land areas needed by this process; on the contrary, processes inherent to the other raw materials did not seem to influence results considerably;
- a slight reduction on the damage to the Ecosystem Quality during the brewing process was due to the positive contribution of the recalled use of by-products from this stage for cattle feeding;
- impacts caused by groundwater extraction were practically negligible under the assumptions made.

3.2 Monte Carlo analysis

The check of the results uncertainty made using a Monte Carlo analysis showed that the most significant uncertainty was due to the barley cultivation process recalled from the Ecoinvent database [19]. The uncertainty of this process, which occurs in the preliminary common phase in both the life cycles considered, affected the Land Use impact category significantly and, consequently, the Ecosystem Quality damage category, as well as the evaluation of the final Single Score for any single situation considered. This high level of uncertainty did not influence significantly the comparison between the two examined situations and therefore the better environmental performance of kegs was confirmed also in Monte Carlo approach. In **Fig. 4** the distribution of the difference between Single Score of 1 L of bottled beer and Single Score of 1 L of kegged beer (afterwards abbreviated as SSD, Single Score Difference) is reported: the prevailing black columns refer to the runs in which the beer in keg life cycle showed a lower environmental load while the white columns refer to the runs in which the beer in bottle life cycle appeared the better option.

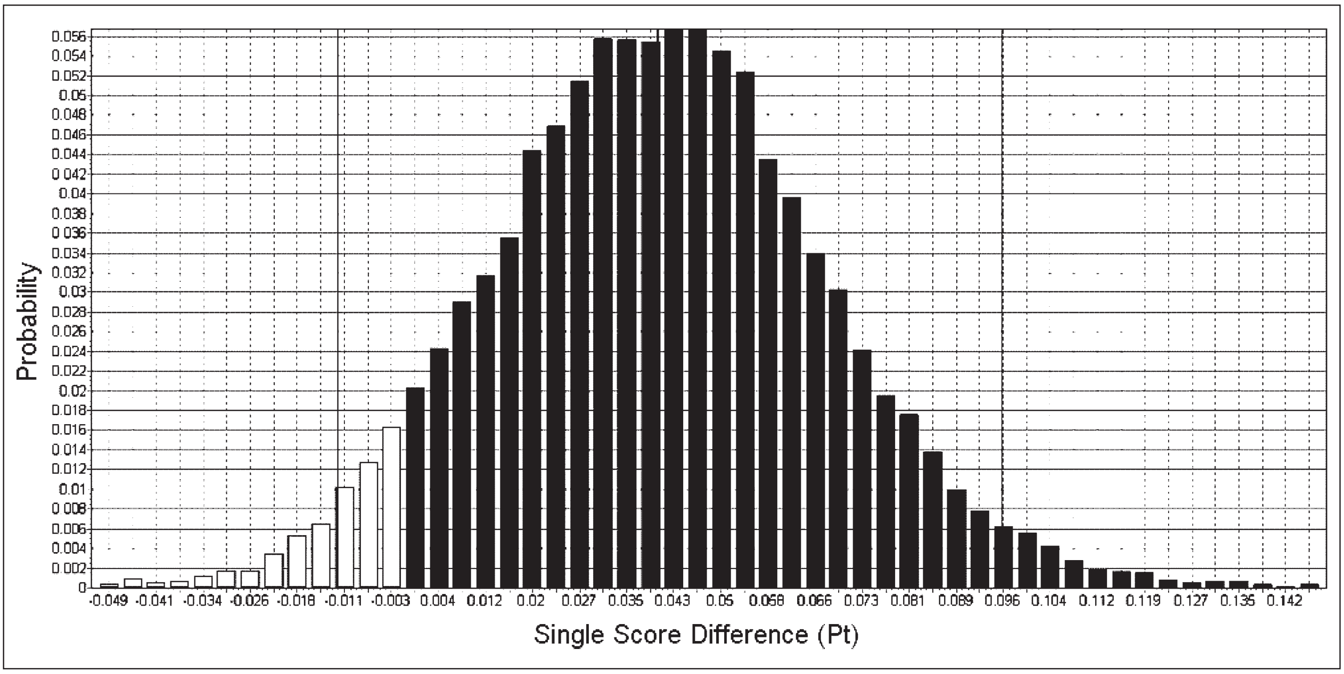

Fig. 4: Probability distribution of the Single Score Difference between the two life cycles calculated with Monte Carlo analysis

3.3 Evaluation of the cultural perspective

Since different assessments could arise from different points of view, Level 1 comparison was repeated with the other cultural perspectives considered in Eco-Indicator'99. The main results obtained with the Egalitarian perspective and the Individualist one are reported in Table 3. When compared with the results obtained following the Hierarchist perspective, no significant differences resulted in the case of the Egalitarian perspective, while large differences occurred in the case of the Individualist one. In fact, the Individualists consider only Minerals among the Resources damage category: therefore, in this context, a metallic keg, even if reusable, assumed higher incidence than a bottle of glass as a consequence of the different scarcity of raw materials needed. Furthermore, the Individualists do not believe that Fossil fuels consumption is a problem since they think it will be possible to substitute totally this energy source when it will be over. It is apparent as this choice seems unwise in the present situation for the general concern about energetic supplies.

3.4 Level 2 comparison

As the last stage of the study, the analysis was repeated with the Hierarchist Eco-Indicator'99 in order to evaluate the influence of the beer consumption phase. This stage, indeed, has a strategic relevance in a LCA study although it occurs in extremely variable ways. Then, energy consumption for beer refrigeration and dispensing, consumer displacement and treatment of the consumer wastewater were included in the analysis. 1 L of beer was assumed to be drunk in an Italian pub by 4 persons that travel together by a car to the dispensing location. 5 km of travel by car and 15.75 L of wastewaters were considered for both the life cycles; moreover, 8.24 Wh and 5.56 Wh of electricity consumption were allocated to 1 L of bottled beer and 1 L of draught beer, respectively. The percentage increases of Eco-Indicators, Single Score and SSD, deriving from these inclusions, are reported in **Table 4**, although the scenario variability and some necessary approximations should have made preferable a purely qualitative interpretation of the results. Under the simple assumptions previously made, the environmental performance difference remained almost constant. It is however worth noting that the beer consumption phase, when considered, gives a significant contribution to the impacts, mainly as the effect of the car use, whose impacts are strongly linked to fossil fuel consumption, both as resource consumption and as combustion emissions. This result proves that brewing, by itself, is a process 'cleaner' and more 'eco-friendly' than other common human activities. On the other side, it calls for attention in further studies on the key role of use phase and individual behaviour.

Table 4: Percentage increase of Eco-Indicators, Single Scores and Single Score Difference (SSD) from Level 1 to Level 2 analysis

Life cycle	1 L of beer in bottle	1 L of beer in keg
Human Health	+109%	+178%
Ecosystem Quality	+80.9%	+85.1%
Resources	+133%	+234%
Single Score	+111%	+162%
SSD	+ 0.0666%	

3.5 Improvement analysis

From the previous analysis it turned out that the most effective actions to reduce the environmental burdens of the beer life cycles have to be promoted in the consumption phase, preferring draught beer to bottled one and reducing car use for the consumer displacement.

However, although brewing process did not seem to be the foremost issue, some useful indications may be given also to the producers:

- monitoring, registering and analysing the input and the output streams of the brewery system;
- choosing carefully the suppliers, especially those of barley and glass bottle;
- improving energy saving policies;
- optimizing solutions for the product delivery;
- setting up marketing strategies in favour of reusable packaging rather than non-returnable ones.

4 Conclusions and Recommendations

A LCA analysis was performed considering, in a cradle-to-grave approach, the life cycle of 1 L of lager beer produced by an Italian small brewery: both the production and the 'final use' (i.e. beer consumption) were considered, assuming for the latter one two different packaging options (non returnable glass bottle or returnable keg). The needed data were mostly supplied by the brewing company and completed on the basis of literature information.

The LCI was developed using the SimaPro software and assessed according to Eco-Indicator'99 method, in its different perspectives.

Some conclusions, common to both the packaging options considered, could be drawn:

- inorganic emissions, land use and fossil fuels consumptions were the most critical environmental impacts in the beer life cycle;
- barley cultivation was a very important process and it should be deepened or treated with a better precision; on the other side, secondary processes did not give significant contributions, thus supporting the assumption of neglecting some of them which were made in the definition of the system boundaries;
- brewing process did not result as a critical stage in the beer life cycle and, therefore, the company dimension may not be a crucial element for the overall impact quantification;
- beer consumption may have a significant impact, under the assumptions made at Level 2, due mainly to the consumer displacement.

With regard to the comparison between the two packaging options, beer in keg turned out to cause a lower environmental load along its life cycle than beer in bottle due to the fact that higher emissions and higher energy consumptions were associated to the allocated glass bottles.

It is worth noticing that some results of this study accord with those reported by other papers [11,12], that pointed out the relevance of bottle packaging and agriculture on the overall life cycle of the beer.

Based on the gathered elements, it was then possible to find out useful suggestions to consumers and to producers for a more responsible consumption and a more environment-friendly production through the use of draught beer and of reusable packaging.

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